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Determination of Ecological Status of Some Nkwen Rivers in Bamenda (North-West, Cameroon) by Diatoms Index

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ABSTRACT

Anthropogenic activities more and more degrade wetlands. The management of these wetlands involves analyzing the ecological quality of the water. Diatoms constitute a biological marker widely used in the assessment of waters. The objective of the study was to determine the water quality of the Nkwen rivers by diatom index with a view to their sustainable management. The study took place in 3 rivers from July 2023 to June 2024. Periphytic diatoms were sampled in these rivers by scraping and taken to the laboratory for analysis. It emerged that river 1 was of average quality with an index of 5.11. River 2 was of poor ecological quality with an index of 5.62. River 3 was of very good ecological quality with an index of 2.17. Measures should be taken by public authorities and the council to restore the degraded river 2 and monitor these watercourses using ecological methods by Diatoms to maintain the balance of these hydro-systems.

Keywords: Biological index; Physico-chemistry; Human activities; Water quality; River monitoring; Restoration; Nkwen; Bamenda; Cameroon.

1. Introduction

Wetlands are the most productive environments in the world, harboring the highest associated animal and plant biodiversity [1]. The ecosystem services provided by these wetlands represent the essence of life on earth. Wetlands are considered like an ecological niche for several living beings. They also represent places where marine animals come to lay their eggs. They serve as a place of water regulation during floods, storing excess rainwater, and can also purify wastewater from the bacteria and aquatic plants that develop there. Wetlands can also provide not only food to humans but also raw materials for technological development [2].

Advances in science and technology are increasingly reducing the mortality rate in humans, leading to a high growth rate. Their direct consequence in Sub-Saharan Africa would be a demographic explosion. Faced with the difficulties of management and distribution of natural and food resources by public authorities, the direct consequence is the rural exodus, which leads to overcrowding of large cities [3]. Non-natives who come to cities, wanting to meet their primary needs, namely food and housing, encounter increasing poverty. These difficulties will push them to settle spontaneously and anarchically in the marshy lowlands. On the other hand, poor administrative and municipal management will lead companies to non-compliance with environmental standards and to pollution of waterways by direct dumping of their waste without prior treatment, having the outlet in the lowlands marshy [2]. All these activities lead to the degradation of wetlands, essential to aquatic and terrestrial life. The example being the city of Bamenda where the socio-political crisis led residents of rural areas to settle there anarchically and spontaneously.

In developed countries, wetland management and monitoring methods have been developed with the aim of restoring already degraded environments and monitoring good quality watercourses. Among these methods, the use of animal and plant communities populating the environment remains best, like Diatom communities [4].

Diatoms are amazing microscopic algae whose typical feature is a siliceous coverage, called frustule, extremely diverse in shape. Diatoms live almost in all types of superficial waters. Depending on their habitats, Diatoms are either planktonic (living suspended on the water), benthic (growing associated with a substrate), or both planktonic and benthic [5].

1.1. Study objectives

In Africa, mainly in Cameroon, work remains scattered and embryonic on the knowledge of Diatoms populating wetlands. It is in this context that it is imperative to know the ecological quality of the rivers in the city of Bamenda. The objective of the study was to determine the ecological status of some Nkwen rivers in Bamenda based on biological indices of Diatoms with the aim of restoring and/or monitoring them for sustainable development.

2. Materials and Methods

2.1. Description of the study area

Bamenda (5°56' - 6°00' N and 10°08' - 10º12' E) is the head quarter of Mezam division in the North-West region of Cameroon (Figure 1). Its relief consists of interspersed plateaus with deep valleys. Its vegetation is the Guinea Savannah type with moderate temperatures. There are two topographic units separated by a high scarp-oriented North-East to South-West [6]. Above the cliff, stands the upper plateau which is mainly Bamenda I and represents 10% of the total area of the city. Altitudes here vary between 1472 m and 1573 m. The climate is the type of humid tropical highland characterized by two seasons: rainy and dry. The temperature here is very cold especially in the morning and evening with the coldest temperature between the periods of January to March with minimum temperature from 14.1-17.8 °C and maximum temperature from 22.5-28.5 °C. Humidity ranging from 39-90% and rainfall from 0.1-14.1 inches of rain per hour. The rainy season is generally longer and lasts for 8 months (mid-March to mid-October) with a short dry season of 4 months (mid-October to mid –March) [7], and mean annual temperature is 19.93 °C. The town has a rich hydrographical network with intense human activities and high population along the different watercourses in the watershed [8].

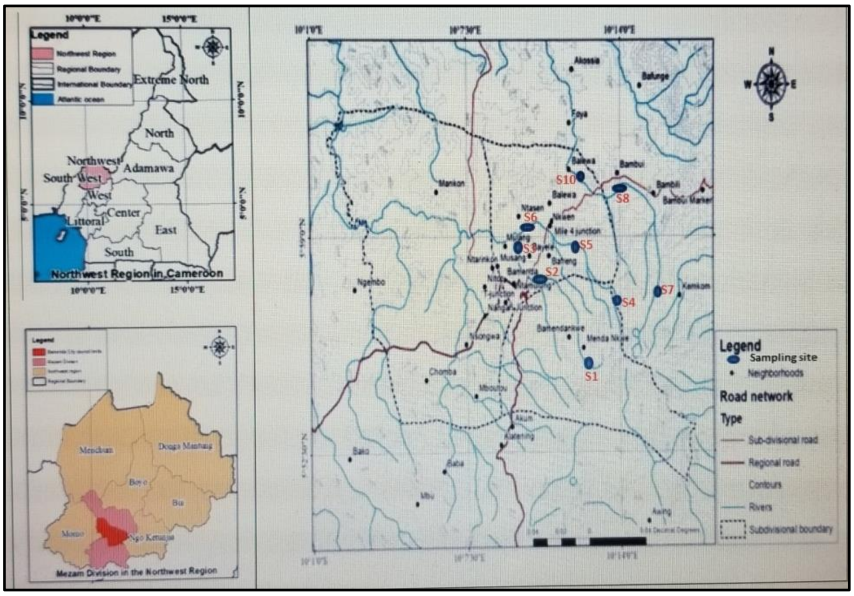

Figure 1. Localization of the study rivers and sites [9] modified

Three (3) rivers were identified in Nkwen according to their degree of exposition to pollutions, and 3 sites (Upstream, middle stream and downstream) were delimited in each river (Table 1). In river 1, pollutants were household waste. In river 2, pollutants were Household waste, organic manure coming from pic and chicken farms, and chemical manure coming from agricultural practices. In river 3, pollutants were very few because of absence or poor anthropogenic activities.

Table 1. Geographical coordinates of study sites

River	Site	Coordinates	Quarters
1	Upstream (1)	5°57’38.4336”N and 10°10’26.5656”E	Menda Nkue
	Middle (2)	5°57’51.3972”N and 10°10’7.7232”E	Bayele
	Downstream (3)	5°58’50.826”N and 10°9’28.818”E	Ndamukong
2	Upstream (4)	5°58’52.2264”N and 10°11’16.2348”E	Ntamuche
	Middle (5)	5°59’14.262”N and 10°10’50.322”E	Kwase, Menda
	Downstream (6)	5°59”49.1892”N and 10°10’21.4824”E	Mbessi
3	Upstream (7)	5°59’22.7724”N and 10°11’29.4468”E	Menteh
	Middle (8)	5°59’58.08696”N and 10°12’26.1918”E	Upper Futru
	Downstream (9)	6°00’22.06944”N and 10°13’1.50456”E	Ntefinki

2.2. Determination of physicochemical parameters associated to the study sites

The physicochemical parameters were measured between 8:00 a.m. and 11:00 a.m. in all the sites. The temperature, water electrical conductivity, pH, salinity and total dissolved solids (TDS) were measured with a Temperature/pH/Salinity/Conductivity/TDS multi-parameter meter of OAKTON instruments Trademark. The dissolved oxygen was measured with an Oxymeter of WTW Trademark. Some water samples were collected with polyethylene (PE) bottles of 1.5 l and stored at -5 °C, in darkness inside a cool box for the analysis of nitrates, total phosphorus and biochemical oxygen demand (BOD_5).

2.3. Sampling of diatoms

The solid substrate, such as the surface of stones and submerged plants located in the current water were sampled. The plants were pressed for herbaceous species and scraped for large diameter woody species. The stones located near the watercourses as well as those located in open water for the shallow sites (control and 1) were scraped using a toothbrush. The contents were rinsed in a container with distilled water. The sample was shaken and filtered through a sieve to remove remains of macrophytes, small stones, leaves or other large particles. The contents were fixed with formalin at 5% of its volume.

2.4. Preparation of subsamples and microscopic analysis

Subsamples were taken after homogenization and diluted with distilled water. The coverslips were placed at regular distances on the hot plate. After stirring, 0.5 ml of the contents of the subsample was placed on the coverslips and heated until evaporation. After drying the material, the temperature was increased to carbonize the organic matter

until it turned gray. The coverslips were immersed in distilled water to remove ash. Several preparations were thus carried out with different dilutions. The preparation was mounted between slide and coverslip. This microscopic work includes determining the species and counting the valves of diatoms, such as the small ornamentations of the valves. The following identification keys were used [4, 5, 10, 11]:

2.4.1. Counting

The counting was carried out according to FOEN [4]. After determining the frequent diatoms in a sample, the diatom valves were counted. At least 400 valves were counted. All the valves found during the enumeration were identified, even those of taxa which did not have a D indicator value. The count was carried out on the entire preparation taking into account all the intact valves; whole cells were counted as 2 valves. Among the fragments, those with at least half a valve were counted.

2.4.2. Frequencies of species in the study rivers

The absolute frequency of each species (Fa) is equal to the total number of its occurrences in all the records. The relative frequency (Fr) of a given species is defined as the ratio of its absolute frequency (Fa) to the total number (Nr) of surveys carried out on a given site. It results in the following expression: Fr = Fa/Nr; this value is often expressed as a percentage: Fr (%) = 100.Fa/Nr.

2.4.3. Determination of diatom indices

To assess the state of health of the study river, the Diatom Index DI-CH was calculated on the basis of the counting list obtained according to the following formula [4]: DI-CH = $\sum_{i=1}^{n} DiGiHi/\sum_{n=1}^{n} GiHi$, with DI-CH = Diatom Index (Second calibration); Di = classification value of taxon i based on its auto-ecological preference (indicator value D); Gi = weighting factor of taxon i; Hi = relative frequency of the taxon in percent (= number of valves recorded in the taxon divided by the total number of valves in the sample studied); n = number of taxa in the sample.

3. Results

3.1. Physicochemical parameters in the study sites

Physicochemical parameters were variables in the study rivers (Table 2). According to these parameters, rivers were divided in 3 categories: rivers 2 showed high physicochemical parameters; rivers 1 showed average physicochemical parameters; river 3 showed low physicochemical parameters. Nitrates were variables from 0.810 ± 0.290 mg/l (river 3) to 15.700 ± 3.450 mg/l (river 2). Total phosphorus was variable form 0.016 ± 0.010 mg/l (river 3) to 0.250 ± 0.150 mg/l (river 2). These organic parameters were within tolerance limits, less than 18 mg/l for nitrates and 0.21 mg/l for total phosphorus.

Table 2. Physicochemical parameters in the study rivers

Parameters	**River 1**	**River 2**	**River 3**
Ts (°C)	23.800 ± 4.750ab	23.200 ± 5.320a	24.140 ± 5.150b
TDS (ppm)	52.160 ± 15.500b	125.750 ± 50.540c	15.200 ± 10.750a

Asian Journal of Basic Science & Research
Volume 7, Issue 1, Pages 40-51, January-March 2025

Cond (µS/cm)	103.230 ± 25.450b	198.250 ± 95.450c	23.600 ± 12.550a
Salt (ppm)	68.230 ± 38.450b	85.240 ± 24.450bc	17.320 ± 14.500a
pH	6.680 ± 1.150ab	7.150 ± 0.034c	6.550 ± 0.950a
Oxy (mg/l)	3.480 ± 1.120b	3.250 ± 2.150b	2.540 ± 1.150a
N (mg/l)	8.820 ± 2.110b	15.700 ± 3.450c	0.810 ± 0.290a
Pt (mg/l)	0.180 ± 0.120b	0.250 ± 0.150bc	0.016 ± 0.010a
DBO5 (mg/l)	34.500 ± 10.150b	1230. ± 560c	13.500 9.120a

Ts = temperature, TDS= Total dissolved solids, Cond= Electrical conductivity, pH =hydrogen potential, Oxy = oxydability, N = nitrates, Pt= total phosphorus, DBO_5= Biological demand oxygen; column with same letters mean no significant difference with $p < 0.05$.

3.2. Diatom index of study Rivers

Diatomic index was variable from 2.17 in River 3 to 5.62 in River 2 (Table 3a, b, c). River 1 was of average ecological quality with an index of 5.11. River 2 was of poor ecological quality with an index of 5.62. River 3 was of very good ecological quality with an index of 2.17.

Table 3a. Diatom index of river 1

Species	**Author**	**H**	**D**	**G**	**H×G**	**H×G×D**
Aulacauseira granulata	(Ehrenberg) Simonsen	0.0189	4.5	1	0.0189	0.08505
Caloneis bacillum	(Grunow) Cleve	0.0094	3.0	2	0.0188	0.0564
Coscinodiscus ampuliformis	Ehrenberg	0.0094	1	1	0.0094	0.0094
Coscinodiscus hanzschii	Ehrenberg	0.0377	1	1	0.0377	0.0377
Cyclostephanos sp.	Anderson	0. 0940	1	1	0.0940	0.0940
Cyclotella gamma	Muylaert	0.0189	1	1	0.0189	0.0189
Cyclotella ocellata	Pantocsek	0.0189	2.0	1	0.0189	0.0378
Cyclotella stelligera	Cleve and Grunow	0.0094	1	1	0.0094	0.0094
Cymbella gamma	Cleve	0.0189	1	1	0.0189	0.0189
Cymbella kappii	Cholnoky	0.0094	1	1	0.0094	0.0094
Cymbella naviculiformis	Auerswald	0.0094	1.0	1	0.0094	0.0094
Cymbella ventricosa	Agardh	0.0094	1	1	0.0094	0.0094
Diatoma mesodon	(Ehrenberg) Kützing	0.0283	1.0	4	0.1132	0.1132
Diatoma sigma	Kützing	0.0189	1	1	0.0189	0.0189
Diatoma tenuis	Agardh	0.0094	3.5	2	0.0188	0.0658
Diatomella balfouriana	Greville	0.0094	1	1	0.0094	0.0094
Diploneis eliptica	(Kützing) Cleve	0.0094	3.5	1	0.0094	0.0329

Epithemia adnata	(Kützing) Berbisson	0.0094	2.5	1	0.0094	0.0235
Fragilaria capucina	(Grunow) Lange-Bertalot	0.0189	1.0	4	0.0189	0.0189
Fragilaria monotaenium	Ehrenberg	0.0094	1	1	0.0094	0.0094
Fragilariforma viriscens	Ralfs	0.0094	1	1	0.0094	0.0094
Gomphonema parvulum	(Kützing) Kützing	0.0377	1	1	0.0377	0.0377
Gomphosphaerium sp.	Kützing	0.0189	1	1	0.0189	0.0189
Melosira varians	Agardh	0.0377	4.5	2	0.0754	3.393
Navicula cryptocephala	Kützing	0.1415	4.0	1	0.1415	0.566
Navicula cryptotenelloïdes	Lange-Bertalot	0.0377	4.0	0.5	0.01885	0.0754
Navicula gregaria	Donkin	0.0377	5.5	1	0.0377	0.20735
Navicula lenticularis	Kützing	0.0189	1	1	0.0189	0.0189
Navicula nivalis	Ehrenberg	0.0849	1		0.0189	0.0189
Navicula sp.	Kützing	0.0189	4.0	1	0.0189	0.0756
Nitzschia fonticola	Grunow	0.0094	3.5	1	0.0094	0.0329
Nitzschia sigma	Grunow	0.0094	1	1	0.0094	0.0094
Pinnularia gibba	Ehrenberg	0.0189	7.5	2	0.0378	0.2835
Planothidium lanceolatum	(Brebisson ex Kützing) Lange-Bertalot	0.0094	1	1	0.0094	0.0094
Pinnularia sp.	Kützing	0.0094	1	1	0.0094	0.0094
Pseudostaurosira brevistriata	(Grunow) Williams and Round	0.0094	1	1	0.0094	0.0094
Squeletonema sp.	Kützing	0.0189	1	1	0.0189	0.0189
Stephanodiscus ampulliformis	Hustedt	0.0377	1	1	0.0377	0.0377
Stephanodiscus hantzschuii	(Hustedt) Hakansson and Locker	0.0660	3.5	1	0.0660	0.231
Stephanodiscus sp.	Kützing	0.0094	1	1	0.0094	0.0094
Tabellaria fenestrata	(Lyngb.) Kützing	0.0189	1	1	0.0189	
Tabellaria flocculosa	(Roth) Kützing	0.0377	3.5	1	0.0377	0.13195
Thallassiosira pseudonana	Hasle and Heimdal	0.0094	4.5	1	0.0094	0.0423
		1.00			1.15945	5.93415
D.I			5.1181			

DI-CH = Diatom Index, D = indicator value, G = weighting factor, H = relative frequency.

Asian Journal of Basic Science & Research
Volume 7, Issue 1, Pages 40-51, January-March 2025

Table 3b. Diatom index of river 2

Species	**Author**	**H**	**D**	**G**	**H×G**	**H×G×D**
Achnanthidium sp.	Kützing	0.0059	1	1	0.0059	0.0059
Cocconeis pediculus	Ehrenberg	0.0089	5.5	2	0.0178	0.0979
Cocconeis placentula	Ehrenberg	0.0119	5.0	1	0.0119	0.0595
Cyclotella ocellata	Pantocsek	0.1190	2.0	1	0.1190	0.0238
Coscinodiscus ehrenbergii	Ehrenberg	0.0298	1	1	0.0298	0.0298
Cymatopluera solae	Smith	0.0178	1	1	0.0178	0.0178
Cymbella mesodon	(Ehrenberg) Kützing	0.0595	1	1	0.0595	0.0595
Cymbella ventricosa	Agardh	0.0298	1	1	0.0298	0.0298
Diatoma mesodon	(Ehrenberg) Kützing	0.0119	1	4	0.0476	0.0476
Encyonema siliciacum	(Bleisch) Mann	0.0030	1	1	0.0030	0.0030
Eunotia sp.	Kützing	0.0059	1	1	0.0059	0.0059
Fragilaria construens	(Ehrenberg) Hustedt	0.0059	3.0	2	0.0118	0.0354
Fragilaria cruentus	Kützing	0.0059	1	1	0.0059	0.0059
Fragilaria sp.	Kützing	0.0059	1	1	0.0059	0.0059
Gomphonema designatum	Reichardt	0.0149	1	1	0.0149	0.0149
Gomphonema olivaceum	(Hornemann) Ehrenberg	0. 0590	1	1	0. 0590	0. 0590
Gomphonema sp.	Kützing	0.0030	1	1	0.0030	0.0030
Gyrosigma accuminatum	(Kützing) Rabenh.	0.0030	1	1	0.0030	0.0030
Luticola geoppertiana	(Bleisch) Mann	0.0030	8.O	8	0.024	0.192
Melosira sp.	Kützing	0.0059	1	1	0.0059	0.0059
Melosira varians	Agardh	0.1190	4.5	2	0.238	1.071
Navicula accomoda	Hustedt	0.1369	8.0	8	1.0952	8.7616
Navicula bacillum	Ehrenberg	0.0059	1	1	0.0059	0.0059
Navicula cruxmeridionnalis	Kützing	0.0059	1	1	0.0059	0.0059
Navicula cryptocephala	Kützing	0.2083	4.0	1	0.2083	0.8332
Navicula cryptotelloides	Lange - Bertalot	0.0298	4.0	0.5	0.0149	0.0596
Navicula cuspidata	(Kützing) Kützing	0.0059	7.0	2	0.0118	0.0826
Navicula lenzii	Hustedt	0.0744	4.5	1	0.0744	0.3348
Navicula nivalis	Ehrenberg	0.0446	1	1	0.0446	0.0446

Navicula sp.	Kützing	0.0059	4.0	1	0.0059	0.0236
Navicula subrhynchocephala	Hustedt	0.0030	1	1	0.0030	0.0030
Nitzschia sigma	Kützing	0.0030	1	1	0.0030	0.0030
Synedra ulna	(Nitzsch) Ehrenberg	0.0030	4.0	1	0.0030	0..012
Synura sp.	Kützing	0.0059	1	1	0.0059	0.0059
Thalassiosira psuedonana	Hasle and Heimdal	0.0059	4.5	1	0.0059	0.02655
Tabellaria floculosa	(Roth) Kützing	0.0119	3.5	1	0.0119	0.04165
Pinnularia gibba	Ehrenberg	0.0595	7.5	2	0.119	0.8925
Rhopalodia sp.	Kützing	0.0030	1	1	0.0030	0.0030
		1.00			2.282	12.8449
D.I			5.6288			

DI-CH = Diatom Index, D = indicator value, G = weighting factor, H = relative frequency.

Table 3c. Diatom index of river 3

Species	Author	H	D	G	H×G	H×G×D
Achnanthes exiguoides	Carter	0.0652	1	1	0.0652	0.0652
Achnanthes sp.	Kützing	0.0438	1	1	0.0438	0.0438
Anomoeneis sphaerophora	Pfitzer	0.0869	1	1	0.0869	0.0869
Cymbella sp.	Kützing	0.0869	1	1	0.0869	0.0869
Cymbella turgida	Grunow	0.0438	1	1	0.0438	0.0438
Cymbella ventricosa	Agardh	0.0438	1	1	0.0438	0.0438
Gomphonema sp.	Kützing	0.0438	1	1	0.0438	0.0438
Mastogloia smithii	Grunow	0.0217	1	1	0.0217	0.0217
Navicula cryptocephala	Kützing	0.3261	4.0	1	0.3261	1.3044
Navicula sp.	Kützing	0.0652	4.0	1	0.0652	0.2608
Nitzschia sp.	Kützing	0.0438	1	1	0.0438	0.0438
Pinnularia sp.	Kützing	0.0869	1	1	0.0869	0.0869
Surirella sp.	Kützing	0.0438	1	1	0.0438	0.0438
		1.00			1.0017	2.1756
D.I			2.1719			

DI-CH = Diatom Index, D = indicator value, G = weighting factor, H = relative frequency.

4. Discussion

4.1. Physicochemical parameters determined in the study rivers

Temperature is a critical factor that influences water quality. It affects the physical, chemical, and biological characteristics of water bodies [12]. The temperature in Nkwen rivers ranged from 23 ^oC to 24.5 ^oC. The highest temperature was recorded in river 2. This could be due to urbanization and pollution and into wetlands which lead to increased water temperatures [13]. The lowest temperature in river 1 is surely because there is waterside vegetation cover which reduces the surface of water exposed to light. Thus, the variation of temperature among the sampling rivers was due to anthropogenic activities in the watershed of the study area. The pH of the wetlands ranged from 6 to 7. These results are similar to those of Ndjouondo *et al*. [14]. Many organisms can survive within this pH range. Electrical conductivity was highest in river 2 and lowest in river 3. The electrical conductivity is an indication of the total amount of ionizable salts in solution as it gives a numerical expression of the ability of a solution to conduct electrical current [15]. Electrical conductivity in Nkwen rivers varied from 198.250 to 23.600 µS/cm. This range indicated that the wetland was from fresh water to slightly saline and could support a variety of plant and animal species. Electrical conductivity was positively correlated with salinity and TDS (total dissolved solids) and describes a growing dissolved salt gradient in the environment and confirms that the water of the Nkwen wetlands would be good conductors of electrical current. These results are similar to those of Ndjouondo *et al*. [8] within the same study sites.

The nitrate levels observed in the study rivers were below the WHO limit 50 mg/l [16]. Even though the values of nitrates are lower than the standards, fluctuations of values at the sampling rivers were indicators of human influence on the Nkwen wetlands. River 2 being the most affected could be due to chemical contamination sources from various anthropogenic activities like as runoff from fertilized farmlands, wastewater, decaying plant debris. The results are partially similar with those obtained by Mendi [17] in the Nkwen rivers (0.81-6.45 mg/l) and higher than that obtained by Ndjouondo *et al*. [2] within the Batika River (0.81-1.55 mg/l). Total phosphorus ranged from 0.016-0.250 mg/l, which was less than the classification according to WHO (maximum permissible limit for phosphate is 5 mg/l). This could be due to decomposition of organic matter, urban runoff, and drainage from agricultural land on which fertilizer is used. Excess intake of nutrients causes an explosion of phytoplankton. The results obtained are similar with those obtained by Mendi [17].

4.2. Biological parameters

The Cameroonian law on water protection (Law No. 98/005 of April 14, 1998 relating to the water regime) aims at the overall protection of waters and their various functions as a living environment for plants and animals as well as their sustainable use by humans. The present work would like to implement this task also in the field of water monitoring by developing methods adapted for the different aspects of watercourses in Cameroon as in developed countries.

When assessing the state of watercourses in the context of its application, the examination of Biocenoses is of essential importance in addition to the evaluation of the chemical quality of water and morphological conditions and hydrological. Only the assessment of the biological state finally allows a direct comparison with the ecological

objectives relating to water. Diatoms are particularly suitable for indicating the state of water because their distribution and frequency depend on the substances contained in the water over a fairly long period [4]. Each community of Diatoms is adapted to specific conditions of salinity, pH, light and oxygen and to specific concentrations of organic matter and nutrients. The structure of a Diatom community, that is to say the relative abundance of each of the species present, thus provides a fairly precise indication of the environmental conditions prevailing in a river. A Diatom community integrates all the physicochemical variations that an aquatic environment undergoes over a period of a few weeks. Thus, by sampling a river and analyzing the structure of its Diatom community, it's possible to assess what the environmental conditions are specific to this ecosystem [18].

When a discharge pollutes a watercourse, the structure of the Diatom community changes. The number of Diatoms sensitive to pollution decreases while the number of Diatoms that tolerate pollution increases. If the degradation of the watercourse increases, the sensitive species almost completely disappear in favor of the tolerant species that dominate the algal community [19]. The term Bioindication encompasses biological methods that allow conclusions to be drawn about environmental conditions based on the organisms present [20]. For organisms or communities of organisms to be qualified as bioindicators, their presence, their behavior or their physiological adaptations (= reversible changes of state) must be in as simple and close a relationship as possible with ecological factors (factors of stress). According to FOEN [4], the diatomic index of water quality varies from very good to poor. For this author, water is qualified as "very good" when the diatomic index is between 1.0 and 3.49; "good" when the diatomic index is between 3.5 and 4.49: the ecological objectives are met from the point of view of diatoms. This is an indication that water quality requirements for streams are likely being met. When the index is between 6.5 to 8.0, it is qualified as "poor": the ecological objectives cannot be respected. This is a clear indication that water quality requirements for rivers are also not being met. River 3 was unpolluted because their diatomic indices are between 2.00 and 4.1. They are described as good quality. River 2 has an index of 5.62; it is polluted and of poor quality. What would justify this would be the position of each river based on surrounding human activities. These results are in agreement with those obtained by Ndjouondo *et al*. [2] on the Kambo and Longmayagui rivers. These authors showed that the polluted Longmayagui River shelters water coming from the industrial zone of Douala Bassa, as well as households.

5. Conclusion

The objective of the study was to determine the ecological status of some rivers of Nkwen (Bamenda, Cameroon) by Diatom indices. All measured parameters vary from one river to the other. Results showed that organic parameters (Nitrates and total phosphorus) were within tolerance limits, less than 18 mg/l for nitrates and 0.21 mg/l for total phosphorus. According to the Diatom index, rivers 3 had very good water quality; while river 1 had average water quality; river 2 had bad water quality. Measures would be taken by council for monitoring non-polluted rivers (1, 2, 5 and 6) and restoring polluted river 3 for sustainable development.

6. Recommendations

(i) Riparian should no longer dump household waste directly into rivers without prior treatment. (ii) It is necessary to create at the level of the council a department for permanent monitoring of wetlands based on biological indices

of diatoms. (iii) A planted filter lagoon with macrophytes and algae should be installed in the polluted areas for their restoration. (iv) An hydrosystem tax should be implemented in the exploitation of wetlands to facilitate their management.

Declarations

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Competing Interests Statement

The authors declare no competing financial, professional, or personal interests.

Consent for publication

The authors declare that they consented to the publication of this study.

Authors' contributions

All the authors made an equal contribution in the Conception and design of the work, Data collection, Drafting the article, and Critical revision of the article. All the authors have read and approved the final copy of the manuscript.

Ethical approval and consent to participate

This study does not contain any studies with human or animal subjects performed by any of the authors.

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Asian Journal of Basic Science & Research
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